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35.

THE
DISTRIBUTION OF ARMOUR IN SHIPS OF WAR,

WITH

Special Reference to the relative Advantages and Disadvantages
of the Central Citadel System and the System of a
Complete Belt from Stem to Stern,

BEING

THE SUBSTANCE OF TWO LECTURES

DELIVERED AT

THE ROYAL NAVAL COLLEGE, GREENWICH,

On February 4th and 11th, 1885.

BY

W. E. SMITH, M.I.N.A., ETC., ETC.,

FELLOW OF THE ROYAL SCHOOL OF NAVAL ARCHITECTURE,

ASSISTANT CONSTRUCTOR, ADMIRALTY,

AND

INSTRUCTOR IN NAVAL ARCHITECTURE R.N. COLLEGE GREENWICH



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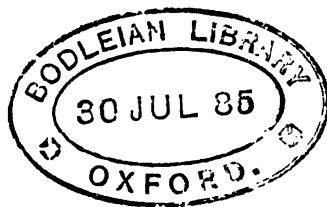
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THESE Lectures were given as part of the Course of Instruction at Greenwich to the Classes of Naval Officers and Constructors studying there.

The subject was chosen on account of the interest taken in it by Captains and Junior Naval Officers, who would find the Naval College a convenient place for discussing differences of view, and gaining information on points not understood.

Mr. Smith's position as Instructor in Naval Architecture at the Royal Naval College makes it unnecessary for me to say anything as to his competence to deal with the question. He would not hold such an appointment if he had not been fitted for the position by long training and experience.

Mr. Smith is in no way responsible for the designs of the English ships which he deals with in the Lectures, although his duties at the designing offices in London, which he performs in addition to those at Greenwich, make him fully acquainted with all the facts. Those who read the lectures carefully will see that as they are not expressions of opinion, but carefully weighed arguments and statements of facts, nothing more is needed from me than an assurance that the facts may be accepted.

To the best of my knowledge and belief they may be.

NATHANIEL BARNABY,

Director of Naval Construction.

DISTRIBUTION OF ARMOUR IN SHIPS OF WAR.

LECTURE I.

THE subject chosen for our consideration this morning is one of the utmost importance to all of us, to Naval Officers and to Naval Architects, alike. The professional reputation of the Naval Architect, and the ability of the Naval Officer to effectually safe-guard his country, are intimately associated in this one question of armour distribution, which is therefore a very fit one for the present audience.

Ever since the introduction of shell guns capable of sending with a fair amount of accuracy powerful incendiary shell, protection of some kind has become a necessity for every ship called upon to face a well-sustained fire from an enterprising enemy.

This protection at first consisted of iron armour and was looked upon mainly as a means of shielding the men and guns in the batteries against serious casualties, and of protecting certain parts of the ship against the incendiary power of common shell. It was neither considered necessary to armour-plate the water-line throughout its entire length, nor to protect the lower parts of the ends of the vessel by strong armoured under-water decks, and such protection therefore was not given.

As examples embodying these ideas we have the "Warrior" and "Black Prince," see Fig. 1, each having a central citadel of armour $4\frac{1}{2}$ inches thick protecting a battery of about 213 feet in length. The total length of ship on the water-line is 380 feet, and the only protection afforded to the lower compartments in the hold at the ends of the vessel is given by a very thin water-tight platform, which can in no sense be considered an armoured deck. Two other examples having about the same proportion of armoured middle part to total length are afforded by the "Resistance" and "Defence," which in respect of armour distribution may be looked upon as small "Warriors," just as "Ajax" and "Agamemnon" may be looked upon, so far as distribution of armour is concerned, as small "Inflexibles."

The introduction of armour and the protection it afforded to the men and guns in the batteries very naturally soon directed attention to the unarmoured ends of the above vessels, and to the want of power possessed by these ships of maintaining their buoyancy and stability, in a way altogether foreign to the way of looking at the question when we were dealing with the old wood ships. In their case no question of buoyancy or stability was ever raised or even thought of, it was simply recognised that their destruction was a mere matter of time, and that their real safety lay in silencing their enemy's fire by their own guns or capturing his ship by boarding, and not in any resistance the wooden sides might be capable of offering.

Attention having been drawn to this side of the question, the vessels next succeeding were made large enough to be armoured on their water-lines throughout their entire length. These comprised the "Agincourt," "Minotaur," and "Northumberland," each of 400 feet in length, and of a displacement of about 10,700 tons. The "Achilles," originally designed like the "Warrior," was altered in the early stages of construction, and was provided with a water-line belt extending from stem to stern. The length of armour protection in these vessels is as under:—

	Length of Water-line.	Length of Armoured Battery.	Length of Belt.
	Feet.	Feet.	Feet.
"Achilles" - - -	380	213	380
"Agincourt" - - -	400	All but 24 feet at bow.	400
"Minotaur" - - -	400	"	400
"Northumberland" - - -	400	185	400

See Figs. 2, 3, and 4.

In two other vessels a contrary development took place, and in these, the "Hector" and "Valiant," see Fig. 5, instead of having an unarmoured battery of less length than the ship associated with a belt at the water-line extending throughout the entire length, we have an armoured battery extending from stem to stern, and a water-line protection stopping about 30 feet short of each end.

During the above early development of the armour question, two other developments were going on which enabled constructors for some time to keep their water-line and battery armour up to and even slightly ahead of the power of the gun. These were, first, the reduction in the number of guns carried in the ship which admitted a reduction

in the size of the battery, and a corresponding thickening of the armour; and, secondly, greatly improved methods of constructing the hull, which enabled weight to be taken from the hull and put into armour.

For these reasons it was possible to build all British ships, of the sizes considered suitable for the Navy, with water-lines completely armoured from stem to stern, and the guns and gunners protected by vertical armour also, which was about equal to the power of the gun at moderate ranges.

These vessels comprised, among others:—

	Maximum Thick- ness of Water-line Armour.
	Inches.
"Bellerophon," single-screw - - - - -	6
"Hercules," single-screw - - - - -	9
"Sultan," single-screw - - - - -	9
"Penelope," twin-screw - - - - -	6
"Audacious," class twin-screw - - - - -	8
"Swiftsure" and "Triumph," single-screw - - - - -	8
"Alexandra," twin-screw - - - - -	12
"Monarch," single-screw - - - - -	7

In these vessels an attempt was made to protect the rudder head, which was entirely exposed in the "Warrior" and contemporary vessels, by dipping the stern down into the water and covering the rudder head. Many of these ships, however, were single-screw vessels, and the protection could not be very good, as on that account the steering gear had of necessity to pass over the top of the blades of the screw.

In 1875 the "Shannon" was launched, having a belt extending right aft to protect the steering gear, the vessel being a single-screw vessel, but the belt stopped 60 feet short of the bow, and the lower part of the fore end of the vessel was protected by an under-water armoured deck, which ran right forward to thoroughly support the ram. The "Nelson" and "Northampton" immediately followed, but being twin-screw ships, the rudder and steering gear could be much better protected by an under-water deck than by side armour, and in these two vessels we have the first examples of the type of water-line protection adopted in the "Admiral" class now building, viz., a central belt amidships and strong under-water decks at the ends.

[The difference between the protection afforded to the steering gear by an under-water deck and a belt is clearly shown in Figs. 6 and 7. The steering gear in the case shown in Fig. 6 is well under a strong protective deck, which is itself a long distance under water. The whole of the gear is supported from the platform next below the protective deck, and has no attachment whatever to the protective deck itself, so that even if this deck were struck it could be driven down to a considerable extent without damaging any of the gear beneath it. Projectiles coming into the ship above the protective deck can do no harm to the steering gear at all.

In the other case shown in Fig. 7 the weakness of the thin belt, as compared with a deck some distance under water, is still further intensified by the necessity of carrying the tiller, &c. above the top of her single screw. The tiller is secured to the protective deck, immediately over it, and a blow on this deck which it will be seen is above water, might disable the steering gear. The steering gear can also be easily reached through the thin side armour. Projectiles striking in the same region in the central citadel ship cannot reach the steering gear.

In the case of a belted ship not being a single-screw ship the gear can, of course, be placed lower, but even then can be much more readily reached through the thin side armour or the above-water deck than through an under-water deck.]

As time went on the penetrating power of the gun continually increased, and although the absolute weight of armour at the disposal of the Naval Architect increased also, the armour rapidly became more and more inadequate for protection under the conditions of close range and a square hit, notwithstanding the thickening made possible by the reduction of its area; and now at the present moment there are guns afloat capable of sending projectiles not only through the thickest armour actually afloat, but through the thickest armour being arranged for in ships building.

It is possible, of course, to design ships armour-proof against all existing guns, and even to leave a margin against future gun development, provided we accept the consequent size of ship. It has, however, been decided everywhere by those persons controlling national expenditures and the sizes of ships, to build even the largest vessels with armour not proof under the above conditions of close range and squareness of hit to guns those ships may have to face.

The problem of the Naval Architect, then, instead of being the very easy one of making a ship proof against all guns actually existing or imagined as being in existence at a future time, and having no restriction placed on the size of his ship, has become the much more difficult one of arranging the imperfections necessarily imposed on his ship by

limiting her size, in such a manner as to allow no kind of imperfection to be so great as to admit of her speedy destruction by any possible mode of attack she is liable to be subjected to, and to produce as well balanced a set of defences against all the various risks his ship has to run as the size placed at his disposal will admit of. *He has to produce the best result on a given size and cost, and he wants to know what the best result is.*

If all persons were perfectly agreed as to the relative values of the various risks to be run by any one ship, we should have advanced a long way towards the best balancing of imperfections. The case, however, is not so easy. As we all well know, the relative importance of the various risks a ship has to run is estimated by each person in a way peculiar to himself, and the suitability of a given set of defences against those risks will also, of course, be judged by each person in the light of what he considers their relative values.

My duty to-day is to explain to you the modes in which the armour defences have been arranged in the principal types of ships, and not simply to express any opinion of my own as to the respective merits and demerits *as a whole* of any one plan. All the plans have good points, and all have bad points. Each particular plan has its own special advantages, and for certain kinds of risk is superior to other plans. For different risks the advantage may change sides, and what was the superior defence may become the inferior defence.

After having explained the various special advantages and disadvantages attached to each plan, I must leave each one of you to draw his own conclusion as to the best plan for general all-round work, and in doing so you must bear in mind that the ship is of necessity imperfect in every single respect. No one feature gives us complete and perfect satisfaction. Every quality of the ship admits of enhancement, and we are not entirely satisfied with any one. A pillar to a roof supports the roof perfectly. We could not replace the pillar by one doing its work better. Every ship could be replaced by another having any one or more of its qualities enhanced, and for this reason we may truly say that a given ship is much too slow, that she does not turn rapidly enough, nor in a small enough space. She does not carry sufficient coal, her guns are too feeble and too few, and take too long to load, and notwithstanding this, she rolls and pitches so much that the few and feeble shots she is able to fire are nearly all wasted, due to this cause alone; and sometimes she cannot open fire at all on account of the heavy seas to which she is exposed. Her armour is too thin,—much too thin, even where it is thickest, and is altogether absent from places where we should like to have at least a little. She is very vulnerable against the ram and torpedo, and her propellers are so much exposed to fouling as to render her incapable of steaming with impunity at a high rate of speed among the floating wreckage incidental to an action, and in spite of all her imperfect defensive powers, her means of saving life as a last resource, viz., her boats, are all so much exposed to machine-gun fire as to be quite useless after a well-contested fight.

I must insist on the above being duly appreciated before going on to describe the armour defences in our battle ships. In a floating body every increase of defence in one direction means either decrease of power in some other direction or else increase of size. I say increase of size, because largeness of size in a ship is looked upon as a defect in itself. The question of cost is, of course, important also, but only involves difficulties which are in our own hands. As soon as the taxpayer and his Naval Advisers agree that it is necessary to spend a large sum of money on a single ship, that money will be forthcoming and the ship built. No agreement between the taxpayer and his Naval Advisers enables a single ship of limited size to have more than a certain limit of defensive and offensive power. The size of a ship to fulfil certain requirements depends partly upon the properties of the materials we find in the market, properties over which we have only a very limited control, and partly upon what might be called the general level of engineering knowledge and professional skill existing at any given moment. At any given instant there are always certain things as impossible to obtain in combination as it is to obtain the moon, and the case of a single ship of limited size having all the qualities that various critics require is of this nature. All this must be clearly realised and willingly conceded before criticising the armour defences in any one vessel, as we must bear in mind that the ship is sadly deficient in other respects,—in respects in the opinion of many critics as important or more important than that of armour protection.

One man, for instance, says: I am willing to take my chance of being sunk just as the individual soldier is willing to take his chance of being shot; but you must give me great speed, plenty of guns, and guns as big as you can make them. I recognise fully that war involves serious risks, but I accept them all, provided you give me ample power of destroying my enemy. If my ship sinks, the other ships carry on my work just as in a land battle the survivors carry on the fight after the loss of their comrades. In my opinion it is as unwise to attempt to make ships invulnerable, or nearly so, as it is to attempt to make soldiers bullet-proof. You must depend upon numbers, and not upon individual invincibility.

Another says: In my opinion the torpedo is my deadliest foe, and therefore you must give me an armoured inner bottom to protect me against torpedoes. I cannot get away from torpedo boats because they outrun me. I go 15 knots, they go 20. I cannot

hope to sink them all by machine guns, or by my own torpedo boats even in daylight, and I cannot keep my torpedo nets down at a high speed. At night and in fogs I am still worse off, as I may not see the torpedo boats at all. You must therefore protect me against torpedoes by a proper construction of the hull, or else my ship, costing three quarters of a million, may be destroyed by the enemy at a cost to him of only a few hundreds.

A third says: I must have a belt of armour at least all round my water-line to protect me against the gun. The gun is not like the torpedo or ram; it cannot be avoided by any skill on my part. My buoyancy and stability must therefore be protected by armour against the gun. The gun must be defeated by resistance as it cannot be by avoidance. The primary duty of the ship is to float and to keep afloat; if she cannot do this she can do nothing, her power is gone. Everything must therefore give way and be subordinated to the necessity of perfect and complete protection to the water-line.

A fourth says: You must protect all my gunners, torpedo-men, and men serving the ammunition against heavy machine-gun fire. The big guns I am willing to risk, they cannot fire very fast, and the practice is sure to be indifferent. My men, however, are only very few, the men who can shoot well are still fewer, and are necessarily among those most exposed. If casualties happen to them I cannot efficiently replace them. The machine-gun bullets will come in a perfect hail, and only a few of them will be sufficient to kill all my men. You must therefore give me good protection against machine guns.

Such a critic does not always remember that machine guns are possible which would perforate the thickest armour of the "Warrior."

A fifth person says: I am fairly satisfied with the offensive and defensive powers of my ship as a whole, but I want many more men under my command than you have given me. I am entirely powerless out of my ship. If I destroy batteries and forts I must still keep to my ship. I cannot land any men; and if I beat my enemy at sea and capture his ship, I cannot take her as a prize into port, because I cannot put enough men on board her to prevent her again falling into the hands of the enemy and at the same time keep my own vessel efficient. I have no choice but to destroy what may be worth nearly a million of money. You must certainly give me many more men.

These examples might be carried much further, but we must let the above suffice.

Now, although all the above things are obtainable in a single ship, provided we make no restriction as regards size, it is a fact that there is no war ship at present in the world even nearly large enough to embrace them all.

If we wanted a belt of armour 24 inches thick amidships and 18 inches thick at the ends, a belt by no means completely gun proof, four 150-ton guns, 12 6-inch guns with a 3-inch side in front of them, a 4-inch inner bottom protection against torpedoes, 10 feet in from outer bottom, and 20 knots speed, we should have a vessel of 20,000 to 25,000 tons displacement, and a cost for completed ship not much short of 2,000,000*l*. The ship, large and costly as she is, is still imperfect; her armour will roll out of the water and under the water. There is no protection against ground mines and the belt, especially at the ends, is still vulnerable. The length of the vessel must be from 500 to 550 feet (*i.e.*, nearly half as long again as "Warrior"), the beam about 75 feet, the mean draught about 28 feet, and the indicated horse power about 30,000. Now, leaving out of consideration all question as regards cost, the size of this vessel, still imperfect, strikes one as being too great for a single officer to command. As regards size she is already almost a fleet. If it were attempted to remedy the deficiencies indicated above, she would be still larger; and she is already so long as to neutralise to a considerable extent the advantage of her speed in ramming her enemy, as she cannot hope to turn so rapidly as a shorter ship.

I have been obliged to treat lightly of the ship as a whole, because otherwise it is quite impossible to intelligently devote consideration to any one feature. Our task is to view the armour defences of our ships under the above limitation of making a well-balanced set of offensive and defensive powers in a ship of limited size. It is very easy to say that the ship carries too little coal, has too little armour, and too little speed, that her guns are too small and too few. It is also easy to show that any given ship could be much strengthened as regards certain specified risks if one feature were developed and the others correspondingly diminished. On the other hand, it is very difficult to show that a given combination represents the best combination for general all-round work. This, however, is the task the designer of a ship has before him when his design is challenged, and in consequence of the variety of the risks to be run by his ship, and the various values put upon those risks by his critics, he can satisfy nobody. Each critic calls the ship defective, because he sees that the particular risk he attaches most importance to could be more safely run by diminishing the power of the ship to meet other risks he thinks more lightly of, and applying the saving in the direction he desires. The result of such criticism can only be that a given ship which perhaps best satisfies as a whole the criticism so freely bestowed upon her has nobody but her designer to defend her. All other persons see only the faults they desire to have removed.

Coming to the actual distribution of armour in the latest types of English battle ships, we may say that they are all central citadel ships, the turret ships having a comparatively high and short central citadel, and the barbette ships a shallower, but longer belt. The armoured length of water-line is given below:—

Name of Ship.	Whether Barbette or Turret.	Length of Citadel.	Length of Ship.	Per-centage of Area of Water-line covered by Armour.
"Inflexible" - -	Turret -	Feet. 110	Feet. 320	42
"Ajax" - -	" -	104	280	45.4
"Colossus" - -	" -	128	325	42.75
"Camperdown" class -	Barbette -	150	330	56.85

The turret ships are compelled to carry their side armour high enough to protect the turning gear actuating the turrets, and as a consequence, a less length of water-line, and a correspondingly less per-centage of its area can be protected by armour than is the case in the barbette ships. In the barbette ships the turning gear is in the barbette itself, and requires no armour on the side of the ship to protect it.

The arrangement of the armour in the turret central citadel ships is clearly shown in Figs. 9 to 9d, which represent the "Agamemnon." A central citadel of armour 104 feet in length reaches from 6 feet under water to the upper deck. This extends longitudinally throughout the length of the engine and boiler rooms, and encloses the two turrets. The maximum thickness of armour is 18 inches, and the top of the side armour is joined by an iron deck 3 inches thick. The ends of the citadel are formed of bulkheads, of nearly the same thickness as the side armour, as shown in Fig. 9b. The midship section of the ship is shown in Fig. 9c, from which we see that the armour is worked "sandwich fashion," that having been considered the best method of working the iron armour in use at that time. The armour in the ships now building is faced with steel, and is made in one thickness.

At the ends of the vessel we have no side armour at all, but a 3-inch under-water deck running from the ends of the central citadel forward to the stem, and most thoroughly supporting the ram, and aft to the stern of the ship to protect the compartments below it. The steering gear and the compartments below the protective deck are as completely protected against the big gun as we can well imagine. It is very difficult for a big-gun projectile to get either through or below this deck on account of its being so far under water. Such projectiles striking the vessel near the water-line simply go through the ship above the deck, and the inflow of water cannot extend below the deck. A big-gun projectile striking a belted ship in the water-line region, where the belt is thin, would get through the thin side armour and be under the protective deck, which is on the top of the belt; there is nothing to prevent the projectile reaching the magazine in the belted ship and blowing up the vessel. This risk the under-water deck of the central citadel ships entirely obviates. Even if the magazine of the belted ship were not blown up, a very large and perhaps fatal quantity of water would find its way into the compartments below the protective deck which in her is above water.

Returning to "Agamemnon" all the magazines, shell-rooms, &c. are under the protective deck, itself under water, and the ammunition is conveyed under cover of the protective deck till it gets within the limits of the central citadel, and is then taken up to the guns; the magazine arrangements are alike in the two ends of the vessel to ensure a prompt supply to the guns, and to enable the action to continue should one end be flooded. The top of the protective deck is covered by coals and other stores, which serve to exclude water when the thin ends are damaged. When the stores are consumed or partially so, and the thin ends riddled, the vessel does not sink so far beyond her load draught of water as when all the stores are in place, as the following table shows:—

Name of Ship.	Sinkage from Load-draught with all Stores and Coals on Under-water Deck in place and Ends riddled.	Ditto, but with Half Coal and Stores in Ends, the other Half being consumed.	Ditto, but with all Coal and Stores in Ends consumed.
	Inches.	Inches.	Inches.
"Inflexible" - - -	23	19	15
"Agamemnon" - - -	23	20	18
"Colossus" - - -	18	16	14
"Collingwood" - - -	17½	15	13
"Camperdown" - - -	14	12	10

At the sides of the vessel on the underwater deck there are two belts of cork clearly shown on Figs. 9b and 9d. These are separated by a "coffer dam," into which packing may be put for limiting the inflow of water when the sides are penetrated.

The stores in the ends on the protective deck are separated into several water-tight compartments, all of which must be destroyed before the sinkages given in the above table can be realised.

In the barbette "Admiral" type of ship we have an arrangement of armour differing from the above somewhat in detail, although the general plan is the same. The barbettes are placed much farther apart than the turrets are in the turret ship, and this necessitates

an increased length of citadel to secure a protected communication between the barbettes and the magazines. The additional area protected by the longer belt allows the cork to be dispensed with.

In these vessels, *see* Figs. 8 to 8d, we have a central belt 150 feet in length and covering 56.35 per cent. of the total area of the water-line. This protects the engines and boilers. The belt is 18 inches thick, is of steel-faced armour, extends to 5 feet under water, and rises 2 feet 6 inches out of water. The top of the belt is joined by a 3-inch steel deck, and the ends of the side armour are joined by bulkheads nearly as thick as the sides of the belt. There is a strong under-water deck at each end as in the turret ship. This deck thoroughly supports the ram and protects the compartments beneath it. The deck is covered with stores in the manner described for the turret ship, and shown clearly at the ends of Fig. 8b.

The deck is subdivided by water-tight bulkheads, and spaces are appropriated for a "water chamber" at each end. This water chamber is an empty space into which water can be voluntarily admitted, and when partially filled it is found as a matter of practical experience at sea,—one having been in use in the "Inflexible" in her recent commission,—that the behaviour of the vessel is much improved as regards rolling. (For further particulars respecting this water chamber, *see* page 15.)

The barbettes are connected to the top of the armoured belt by a circular tube covered with thick armour. All the ammunition to the barrette guns goes through these tubes and remains completely under protection during its whole passage from the magazine to the gun. The loading gear in the barrette is well protected against the big gun, as it is all behind thick inclined steel-faced armour. The men in the barbettes are protected against the big gun by the thick side armour, and against the machine guns in the enemy's tops by a machine gun-proof plate covering the top of barrette. The barrette is protected from shell bursting immediately beneath it by a 3-inch floor shown in Fig. 8. There is a battery of six 6-inch guns and 6-pr. quick firing guns under a light spar deck, and this is protected from raking fire by armoured screens 6 inches thick, reaching from the barrette walls to the sides of the ship. The side in front of these guns is 1 inch thick. Along the top of the deck covering in the belt there is a coal bunker at the side of the ship as shown in the midship section at Figs. 8b and 8c. The section at the end of the ship is shown in Fig. 8d. All the hatches on top of the deck over the belt that are necessarily open when fighting the ship are protected by armoured glacis plates and coffer dams, which rise to a height of more than 5 feet above water.

It is easy to see what the strong points of the above central citadel system are:—

1. The guns and gunners are exceedingly well protected for the size of ship.
2. The ventilating tubes communicating with the boilers and engine-rooms, and the tubes for bringing the ammunition through, are also equally well protected.
3. The engines and boilers are better protected against projectiles than if the same weight were carried along in the shape of a complete belt.
4. The magazines and shell rooms in the ends of the vessel, and the steering gear, are much better protected by the under-water deck than if the sides were armoured with armour not projectile-proof, and the under-water deck removed from where it is underneath the coal and water to the top of a belt above water. The vitals of the ship—her machinery, her powder, or her rudder and steering gear—can only be reached, and the ship disabled by a single blow, provided that blow is much heavier than would suffice if the same weight of armour were more diffused in the shape of a complete belt.
5. For a length of about one half of that of the entire length of the ship, viz., the unarmoured ends, it is a matter of *non-vital* importance whether a big-gun projectile strikes at the water-line or not. In a belted ship such a projectile striking at this point might either blow up the ship or completely flood one end and render the magazine useless. The amount of water admitted would, in the belted ship under the above circumstances, be so great as to render her quite unmanageable and an easy prey to her enemy, even if it did not at once sink her outright. In the central citadel ship the amount of water admitted under these circumstances would be so moderate in amount as to leave the ship, as I shall show further on (*see* page 13), with her sea-going qualities and fighting qualities practically unimpaired.

An incidental advantage of the central citadel system is that the ram is very much better supported by a riveted deck than by side armour attached to the ship only by a comparatively small number of bolts.

It is also easy to see in what respects the above system is defective.

The ends of the vessel being formed only of thin plate are readily penetrable not only by the lightest ship guns proper, but also by machine guns, and this penetrability renders a diminution of speed and stability both possible and probable.

If however we wished to carry the belt to the ends of the vessel and retain unimpaired all her existing qualities we should want considerably more than 1,000 tons additional displacement, and if we did carry the belt to the ends, we should be less safe against certain risks than we now are. The steering gear would be more exposed.

the magazines and shell rooms could be more easily reached, and it would be much more likely that the big gun would completely flood one or both ends of the ship, than when the strong deck was well under water. In attempting to obviate the risk of having a *moderate* quantity of water almost certainly admitted to the ends, we have largely increased the risk of having *fatal* quantities of water admitted, increased the probability of blowing the ship up, or rendering her unmanageable by disabling the steering gear, and have largely increased the size of ship. It is also certain that we have not obviated the particular risk we attempted to, for the belted ship is exposed to precisely the same defect of getting water in on her armour deck, notwithstanding that it is commonly spoken of as being above water, as the central citadel ship is of getting water in on her deck, that is under water. This defect is a defect common to both types of vessel, and not peculiar to the central citadel ship, as I now proceed to show.

If all the light projectiles reaching the two types of ship were to strike them only in the region marked by the belt in the belted ship, the belted ship would not suffer at all, and the central citadel ship would have a certain quantity of water admitted into her interior. For light projectiles striking the two types in any other parts there is nothing to choose between them, both are exactly on the same footing.

Fig. 8c represents the "Camperdown" constructed with a complete belt from stem to stern. The wave shown on it is that raised by "Collingwood" on her recent steam trials. Any projectile striking the bow under the wave as shown, admits water to the vessel just as freely as in the under water deck central citadel ship, if the projectile strike amidships just above the belt, the hole, in any seaway, is under water a great deal on account of the rolling of the vessel and the passage of waves along her sides. Large quantities of water may therefore find an entrance into the vessel, and it must be clearly realised that the alternation of the belt going under water and coming out of the water offers no impediment whatever to the accumulation of a fatal quantity of water. Unless the hole can be stopped or the inflow of water be prevented from obtaining a free access to the interior of the vessel upon the armoured deck by water-tight subdivisions still remaining intact and undamaged, it is incontestable that the water must come in faster than it can go out, the water will accumulate and capsize the vessel,—a defect which is said by some to be peculiar to the central citadel ship. A reference to Fig. 10 will show that the above statement is true. The rate at which water enters and leaves the holes is determined by the difference of level between the external and internal water, and this may be considerable, and depends on the extent to which the vessel is rolling and the kind of waves that pass her. The rate at which the water leaves the hole depends upon its height above the hole. As soon as the hole gets fairly out of the water the internal water, under the assumed circumstances of having no available water-tight sub-division left, lurches over to the other side. It cannot escape through the hole above water, because it leaves it for the other side; it cannot escape through the hole it finds there, because the external water is higher than the internal water. The vessel, therefore, very soon capsizes. In a matter so important as this I do not want to appeal to you through the medium of diagrams, or what may appear to some of you as abstruse reasoning. I will demonstrate the above by the aid of a model. This model, Fig. 11, represents in all essential respects a ship with her water-line completely protected by a belt rising 2 feet 6 inches above still-water level. There are a series of holes in the model at present plugged up, and there is no internal water-tight sub-division left above the belt deck, that being supposed all destroyed by light guns. The ship is undamaged in other respects. Her belt is unpierced, the belt deck, has no holes in it, and the hold compartments are quite intact. Leaving the plugs in and rolling the model,* you see she behaves as a ship should do. I now take out all the plugs, and the vessel still floats perfectly upright as before, because all the holes are above water, and the water is still. If I gently agitate the water so as to slightly disturb its surface, you see what happens—the vessel capsizes almost at once. Any consideration, therefore, of the effect of water on the decks of a central citadel ship must be given with a full recognition of the fact that water is as injurious in the belted ship, and that the belted ship has only the same unarmoured defence against fatal quantities of water being admitted as the central citadel ship has. The practical question for consideration is not, therefore, "Could we not escape all danger of this kind by making our ships a little larger, and giving them a belt all along the water-line?" but, "Is there sufficient speed, stability and buoyancy in the central citadel ship to ensure a reasonable probability of survival in action?" The answer to the first question we have just seen, as demonstrated by the model, is *no*; the answer to the second question I will endeavour to show you is *yes*. I am, of course, compelled to say a reasonable probability, because from the nature of the case certainty of survival is unattainable. After everything has been done the ship will have to run some risk she can ill afford to run. Absolute safety she cannot have; she must be satisfied with less. That probability of survival could of course be increased by enhancing her present defensive powers, either by increased size or by diminution of some other quality in the ship.

Let us, then, consider the behaviour of the central citadel ship a little more closely.

* This experiment was performed in a tank of water in sight of the audience.

To understand the principles regulating the sinkage of these ships when their unarmoured ends are perforated and the whole of the internal water-tight subdivision completely destroyed, let us consider the simple case shown in Fig. 13.

It is a well-demonstrated truth that the weight of all floating bodies is equal to the weight of the fluid displaced by them. All bodies of the same weight must, therefore, have the same volume of displacement, no matter what their shapes may be, and if a body of given weight loses displacement in one place it must be made up in another. Corresponding to a given fixed weight we must have a given fixed volume of displacement. In the figure the volume of the displacement while the vessel is intact and undamaged is—

$$A + B + C + D + E.$$

If we make holes between the water-line W. L. and the under-water deck, the sea will find its way into the interior and fill the interstices between the stores. The vessel can only be kept at the water-line W. L. by the aid of a sky purchase P. Suppose such a purchase provided. The strain on the purchase is evidently the weight of water that comes in on top of the armour deck and fills the spaces between the stores. The amount of water that comes in is quite independent, it will be noticed, of the nature of the stores on the deck, but only depends on the volume unoccupied by the stores themselves. So long as this volume remains unchanged the stores may be as heavy as lead, or as light as feathers, without making any difference to the amount of water that comes in or the strain on the sky purchase P. The loss of volume of displacement occasioned by the entry of water we may call v .

If we gradually slacken the sky purchase P. the vessel will sink in the water till the additional volume of displacement between W. L. and her new water-line is equal to v . The necessary amount of sinkage to ensure this depends on the area of water-line still capable of displacing water as the vessel sinks into it. This area is the area of the armoured central belt + a certain fraction of the unarmoured ends depending on the proportion of space in these ends occupied by solid water-excluding stores. If the space is half filled we must take half the area, if three-fourths we must take three-fourths, and so on. If, then, A be the area of the central belt, a the area of that portion of the unarmoured ends still available for displacing water as the vessel sinks lower into it, the additional volume of displacement due to a given sinkage, s , must of necessity be $= (A + a)s$. The sinkage due to the riddling of the unarmoured ends is therefore $= \frac{v}{A + a}$ = the volume of the interstices between the under-water deck and the

original water-line W. L., divided by what we may call the effective area of the water-line, after allowing for the ends being damaged. The new water-line is at a height s above W. L., but is not shown on the diagram.

The above principle has been many times tested by actual trials with models, and its soundness is beyond question. The principle has been applied to the following typical vessels, with the results stated against each. The sinkage of these same vessels due to coaling has been added for information and comparison:—

					Sinkage due to Riddling the Unarmoured Ends, estimated as above.	Sinking due to Coaling.
					Inches.	Inches.
"Warrior"	-	-	-	-	32	16
"Resistance"	-	-	-	-	42	16
"Inflexible"	-	-	-	-	23	27
"Agamemnon"	-	-	-	-	22	20
"Colossus"	-	-	-	-	18	22
"Collingwood"	-	-	-	-	18	22
"Camperdown"	-	-	-	-	14	22

Beginning with the "Inflexible" in the above table, we see that the sinkage due to the riddling of the ends, and the complete destruction of the numerous water-tight subdivisions is less than that she experiences every time she coals. In "Agamemnon" the sinkage is slightly greater, in the "Colossus" and "Collingwood" the sinkage is again less, and in "Camperdown" the sinkage due to coaling is 50 per cent. greater than that due to riddling. In "Warrior" and "Resistance" it will be noticed that the sinkage due to riddling is twice that due to coaling.

The table on next page gives much more detailed information on this subject.

If both ends of the ship be freely riddled and the whole of the subdivisional bulk-heads on the under-water deck completely destroyed, the sinkage is less, and in some cases much less than that due to coaling. The amount of sinkage due to riddling is not great in itself, and unless it involves the loss of seagoing and fighting qualities in the ship, cannot in itself be objected to. This feature of the case I now proceed to deal with.

If only one end be riddled the ship will change trim unless water be voluntarily admitted to the other end, and for which provision has been made. This change of trim can easily be calculated by the Naval Architect, or can be experimentally

ascertained by means of a model. Both methods have been resorted to in the case of "Inflexible" with concurrent results. The change of trim is in no case sufficient to cause even much inconvenience on board and does not imperil the ship in the slightest degree. In "Agamemnon" the water-line with the fore end only riddled is shown by *c. d.* in Fig 9. It will be noticed that the fore end has not gone down much, and that the stern has not lifted to such an extent as to imperil the rudder or the propeller blades. This tipping can easily be seen by the aid of this model, *see* Fig. 12, which represents in all essential features the "Admiral" type of vessel. We have a central citadel, under-water decks, covered by wood battens to an extent representing the proportion of the space occupied by the stores and coal stowed in them, and similar wood battens in the space on the belt deck appropriated to coal bunkers. The midship section of the vessel is precisely that of the model of the belted ship, and is given in Fig. 11*b*. The armour reaches only 2 ft. 6 ins. out of water as in the belted ship, and in the model covers 50 per cent. of the area of the water-line. In the "Admiral" vessels 56·35 per cent. is covered by armour.

Name of Ship.	Area of Load-Water-line.	Per-centage of Water-line Area covered by Armour.	Per-centage of Water-line Area included in Coal Bunkers beyond Armour.	Per-centage of Water-line Area included in Cork Chambers.	Remaining Per-centage.	Per-centage of Cubic Contents of Spaces in previous Column occupied by Stores other than Coal and Cork.	Buoyancy lost by complete Riddling of unarmoured Ends with Cork intact, and all Coal and Stores in Ends.	Sinkage of Ship corresponding to previous Column.	Buoyancy lost by complete Riddling of unarmoured Ends with Cork intact, and one Half of Coals and Stores in Ends expended.	Sinkage of Ship corresponding to previous Column.	Buoyancy lost by complete Riddling of unarmoured Ends with Cork intact, but all Coals and Stores in Ends expended.	Sinkage of Ship corresponding to previous Column.	Load-draught of Water of Ship from which Sinkages are reckoned.	Displacement at load-draught.
	Sq. Ft.						Tons.	Ins.	Tons.	Ins.	Tons.	Ins.	Ft. Ins.	Tons.
"Inflexible" -	19,000	42	30	11·4	16·6	25·4	750	23	760	19	770	15	25 3	11,880
"Agamemnon" -	14,880	45·4	18·5	12·85	23·25	24·5	580	22	580	20	580	18	23 6	8,510
"Colossus" -	17,100	42·75	26·85	13·0	18·4	22·8	570	18	555	16	540	14	25 9	9,150
"Collingwood" -	17,100	54·15	17·4	None	28·45	22·8	500	17½	500	15	500	13	25 9	9,150
"Camperdown" -	17,850	56·35	17·0	None	26·65	21·0	420	14	425	12	430	10	26 9	10,000

* All these sinkages are reckoned from the load-draught given in the last column but one.

Allowing the water to come in at one end only, she tips, as you see, only slightly, allowing it to come at both she sinks bodily, but leaves her armour still above water. We may therefore feel perfectly certain that so far as increase of immersion is concerned the central citadel ship is quite safe with either or both ends completely riddled.

The same two courses may be followed with respect to her stability. The Naval Architect may either calculate the stability of his vessel in any assumed condition of damage, or he may ascertain the same thing experimentally by the aid of an accurate model. Both these methods have been resorted to in the case of "Inflexible" with perfectly harmonious results.

The stability of a vessel is usually represented by what is called "a curve of stability," the construction of which will be readily understood from Fig. 14. When inclined over at a given angle of inclination, the weight of the vessel acts vertically downwards through G the centre of gravity of the ship, and the support of the water acts along the line marked "line of buoyancy." These two lines have a perpendicular distance, G Z, between them, the length of which is an exact measure of the amount of stability the vessel has in the condition assumed. When G Z is great the stability is great also, and when small the stability is small. The weight of the vessel always acts through G, the centre of gravity of the vessel, at all angles of inclination. The determination of the amount of stability a vessel has in a given condition and at a given angle of inclination depends simply upon an arithmetical calculation of the position of the line marked "line of buoyancy." The length of G Z is calculated for various angles, and the results set off graphically as shown in the shape of a curve, which is appropriately called a curve of stability.

The curves of stability of "Inflexible" for various conditions of ship are given in Fig. 18. The soundness of the principles on which these curves were calculated was examined by the members of the "Inflexible" Committee, consisting of:—

Admiral Sir J. Hope, President.
Dr. Woolley,
G. W. Rendel, Esq.,
W. Froude, Esq.

This Committee considered the soundness of these principles unassailable, and further considered that the amount of stability the vessel had was sufficient. In their report they said "*e* or *f* might fairly be assumed to represent the greatest amount of damage

" the ship would be likely to suffer in action. This represents the unprotected ends
 " completely riddled and waterlogged, but the materials and cork remaining and adding
 " buoyancy. In *e* the whole of the coal is assumed in place, in *f* it is assumed to be
 " removed. If reduced to this condition the ship would possess both buoyancy and
 " stability enough to face all contingencies of weather. The united movement of all
 " her guns from the loading to the firing position would not heel her more than $2\frac{1}{4}^{\circ}$.
 " It cannot be said that the armoured citadel is invulnerable, or that
 " the unarmoured ends are indestructible, although the character of the risks they run is
 " different. But, in our opinion, the unprotected ends are as well able as the armoured
 " citadel to bear the part assigned to them in encountering the risks of naval warfare,
 " and therefore we think that a just balance has been maintained in the design, so that
 " out of a given set of conditions a good result has been obtained."†

This Report was signed December 4th, 1877.

A previous Committee, presided over by Lord Dufferin, reported in 1871 that the
 " only method of bringing about a well-considered armour-plated ship was to have a
 " central belt and raft ends with an under-water deck." Two naval members of the
 Committee, Admiral Ryder and Admiral Elliot, went much further in this direction, and
 advocated the entire abolition of side armour for the protection of buoyancy and
 stability, and to employ armour-plating only for the protection of guns and gunners.
 The water-line was to be protected by a cellular structure only. The members of this
 Committee were:—

Lord Dufferin, President.

Sir W. Thomson.

Admiral Elliot.

Admiral Ryder. } These two members recommended the entire abandonment of

Admiral Hornby.

Admiral Stewart.

Dr. Woolley.

Professor Rankine.

W. Froude, Esq.

Captain Hood.

Captain Goodenough.

G. W. Rendel, Esq.

Peter Denny, Esq.

C. P. Bidder, Esq.

T. Lloyd, Esq.

We therefore have it on record that the above Committee deliberately formed the
 opinion that the central citadel ship, with under-water decks at the ends was the best
 ship that could be devised for encountering the varied risks of naval warfare. This
 opinion was arrived at after hearing all that could be said on the subject by any person
 who had anything to say. The above two Committees had seven naval members, all of
 flag rank, except two. Two flag officers dissented from the above only to the extent
 of giving up even the central armoured belt amidships. So far from objecting to the
 unarmoured ends, they were willing that the water-line should have no armour at all.

I do not, however, wish you to be guided in this important matter merely by the
 weight of authority, however great that authority may be. You may say, too, that the
 conditions have changed since the above reports. Let us assume, then, that on account
 of the development of the machine gun, the quick-firing 6-pr., and the introduction of
 the smaller breech-loading guns, that we must have adequate protection against these
 weapons. Such protection, of course, is much to be desired, if we can afford it. Other
 increases of defence are also desirable. It is not so easy to give protection against the
 above guns, as some suppose. It is quite certain that the addition of a complete belt
 along the whole length of water-line does not give us this protection.

If an enemy can destroy the unarmoured upper works of a ship, as some say is
 almost certain to be the case, the only conclusion we can come to is, that the belted ship,
 although less safe in other respects than the central citadel ship, is no safer in this one
 respect of being capsizable by light guns only.

Let us take a completely belted ship, such as that in Fig. 11. It is easy to see at once,
 that apart from her unarmoured upper works, she is a low freeboard vessel and has
 no useful range of stability.

All foreign vessels of this type, like their English rivals, depend for their stability in a
 well-contested action on the improbability of their unarmoured upper works being
 completely destroyed. If their unarmoured upper works are opened up freely to the
 sea they will capsize quite easily, in spite of their belt, as I have previously shown. See
 page 9. The floating models before you show very clearly that these vessels depend

* The "Monarch," when her coal is consumed, heels nearly 5° , due to this cause, when she is intact and undamaged.

† The question of speed is dealt with on page 16.

for their stability on their unarmoured upper works.* I do not want to leave an impression on your minds, from having witnessed these experiments, that the belted ship is less safe against the machine-gun and small-gun risk, than the central citadel ship is, or that you would easily capsize the belted ship if she were your enemy in an action by accomplishing the complete destruction of her upper works, as supposed in the model. I am only showing that it is altogether wrong to suppose, as some do, that the possession of a completely armoured water-line takes away all anxiety as regards light gun-fire. It is perfectly true that the "Admiral" type of ship is destructible by light guns if they have time enough. It is perfectly true, also, that the belted ship is destructible by the same weapons, and has no chance of being destroyed by the big gun. So much for the complete destruction of the upper works in both types of ship.

When the damage stops short of completeness it is purely arbitrary to say we should provide that a certain amount of stability should be left when specified parts are penetrated. All assumptions that may be made as to the probable damage a ship may experience are open to objection. All such assumptions are mere guess-work, and probably no two persons would agree in making them. The best method is to look at the matter generally, and not in any specified precise way. Adopting this plan, we may say that in our English "Admiral" type a very large proportion of the unarmoured upper works must be destroyed to reduce the range of stability to 30°, and even when this has been done the vessels will, in the words of the "Inflexible" Committee, be able to face all contingencies of weather.

The stability of our battle ships depending so much on their unarmoured parts, it is important to make these unarmoured parts as efficient as possible for the purpose. In the English battle ship this unarmoured defence has been made as great as possible by the suitable disposition of water-excluding stores,—the coal, cables, provisions, and in some cases of cork,—most of which are well protected by being under water.

I do not know the exact nature of the unarmoured defences in the belted ships of the world, but the model experiments you have seen show that it is quite certain they are as much needed in their case as in the case of the central citadel ship.

LECTURE II.

We have seen for ourselves how the stability of the central citadel ship and of the belted ship stands in smooth water, and we have also seen what the "Inflexible" Committee thought of the sufficiency of the stability of that ship to provide safety against stress of weather and sea. Let us now look a little into the matter ourselves and ascertain the grounds of safety at sea.

It must be a perfectly well-known thing to everybody here that if we take a pendulum or a man in a swing and carefully time our impulses we shall certainly get the pendulum over its point of suspension, no matter how feeble our impulses may be, always provided they are kept up long enough and that there is no resistance. If the resistance is very great, due to the pivot being jammed or to the pendulum having to vibrate in a fluid, it may not be possible to capsize the pendulum even with the most sustained and most carefully timed impulses. The resistance might be too great for the applied force to overcome even if it could be kept up without flagging. If the applied force were too small in relation to the stability or resistance or could not be kept up long enough the pendulum might be perfectly safe against capsizing.

In the case of a ship 1,500 miles from port we cannot depend upon the capsizing forces not being kept up long enough, the sea is untiring, and therefore our only safety lies in having a sufficient amount of stability and resistance to rolling. The stability and resistance to rolling are in our own hands, and we may make them, within certain limits, what we please. The motion of the sea is beyond our control; this we have to contend with as best we may.

I must ask you to bear in mind what is so frequently lost sight of, viz., that both resistance to rolling and stability are necessary to safeguard a ship against capsizing

* The two models were floated in a tank. The whole of the upper works of the belted ship were supposed to be freely open to the sea, having been completely perforated by light guns. The ship was shown to be certain to capsize in any seaway, or even by steaming ahead in smooth water. The central citadel ship was shown in a condition with all the water-tight subdivisions before and abaft the belt completely destroyed from the under-water armoured deck upwards. The side in front of the 6-inch breech-loading guns was also supposed destroyed, and of no use for the exclusion of water. The side in front of the belt of coal was also supposed destroyed, but the inner bulkhead remaining intact. In this condition, involving the complete destruction of all the unarmoured upper works of the vessel right through from stem to stern, and from the armour belt and armour decks upwards, with the single exception of that portion of the ship comprised between the inner coal bunker bulkhead on one side to the similar bulkhead in the other, the model could not be capsized by any sea that could be raised or even by pushing her ahead very violently. If the destruction done to this ship had been completed, as was done in the belted ship, she also would have easily capsized under the same treatment.

These experiments show that both types can be sunk by simply destroying their unarmoured upper works, and show further that the central citadel ship with an amount of destruction done to her unarmoured upper works only just stopping short of absolute completeness will be quite safe in a seaway, and can be steamed ahead without capsizing.

at sea. No amount of stability, apart from resistance, could give a well-founded assurance of safety, and no amount of resistance to rolling apart from stability is sufficient to safeguard the ship. We must have a combination of both.

The stability of a vessel, apart from resistance to rolling, is a thing that effectually safeguards the ship from capsizing only in still water under steady inclining forces, such as having a deck load on one side of the vessel or a wing compartment filled with coal or water. In a seaway the stability depends for its value on the extent to which it is associated with resistance to rolling. The more and more the resistance to rolling is increased, the more and more does a given amount of stability assure the safety of the vessel. The more the resistance increases, the less is the needful amount of stability to ensure safety against capsizing by the heave of the sea. With an increased resistance to rolling a small amount of stability may leave just as large a margin of safety as a larger amount of stability and a decreased amount of resistance. With no resistance to rolling all vessels would be unsafe under circumstances to which they might at any time be exposed.

Coming back to our pendulum; we could baffle the efforts of a man to capsize it, either by loading it more heavily and increasing its stability, or by leaving its stability alone or even decreasing it, provided we jam the pivots harder, and increase its resistance to oscillation.

Now this increase of resistance to rolling is precisely that which happens when we perforate the ends of the central citadel vessel and reduce her stability. As the ship rolls, the water in her ends dashes about from side to side and increases her resistance to rolling to such an extent that under these circumstances the vessel will roll much less than when intact and undamaged, and be in no more danger of capsizing than before her ends were wounded.

This power of the water to reduce rolling has, I know, been looked upon with a very scanty amount of belief by many persons, as being contrary to a practical seaman's judgment, but here is an experiment to show you that the statement is beyond question.

[At this point of the lecture the models illustrated in Figs. 16 and 17 were used. The models represented the midship sections of the "Admiral" class, and were both of the same weight and size. Each model was mounted on trunnions, marked T, and both oscillated freely on these trunnions in exactly the same time. The models were placed one behind the other, so that the parallelism of the masts was evident to the audience. The model in Fig. 17 was provided with a glass tube into which varying quantities of water could be put. An amount of water representing $\frac{1}{100}$ th of the total weight of the model, i.e., 100 tons in a 10,000-ton ship, was now placed in the tube, the models were started from the same angle as before, and the model with the loose water, instead of keeping up exactly with the other, or rolling more violently, came almost instantaneously to rest.]

Notwithstanding the result of the above experiment, there may be some persons in the room who are still dissatisfied as to the power of the water to moderate the rolling of a ship at sea. Such persons may say I cannot disprove the accuracy of your experiment, but I am satisfied there is some error in your inference, because your inference does not accord with my practical experience at sea. My experience at sea teaches me that if one of my guns, for instance, takes charge, the ship at once rolls more violently in consequence, and if there is any truth in your theory, the reverse ought to take place; the ship ought to be steadied by the motion of the gun.

I have no hesitation at all in saying that the motion of the ship is steadied by the motion of the gun, and here is an experiment to prove it.

[The model shown in Fig. 16 was provided with a grooved traverse in which a marble, M, could freely run from side to side. The marble was stopped at each end of its roll by the hoods, H. The weight of the marble was on the scale of 100 tons for a 10,000-ton ship. The tube in model, Fig. 17, was emptied of water; the marble put in model, Fig. 16, and the two models started from the same angle as before. The model with the marble freely traversing the deck came almost at once to rest.]

As regards the shot or gun at sea, its effect is baneful as regards the ship's structure and men's legs, but beneficial as regards the violence of rolling.

There may also be some persons in the room who will say, I admit all that you say you have done, but that does not cover my point. You have taken 100 tons of water or 100 tons of gun and shown that that quantity effectually moderates the rolling. I have never doubted that it would. You may, however, have 600 tons of water on deck, and if you do, what will happen then? I may take one grain of arsenic with perfect safety or even with advantage, but what will happen if I take six? As regards the arsenic I am not competent to answer that question; but I can tell you what will happen if you increase the amount of water. The action of the water in moderating the rolling depends entirely on the possibility of its moving; if the space is full and the water in consequence cannot move you get no more effect than if the water were so many tons of pig ballast, and here is an experiment to prove it.

[The tube in model, Fig. 17, was here filled with varying quantities of water, and the effect was always to stop the model much sooner than the model with no weights free to move. The two models were always started from the same angle, so that their

relative behaviour could be easily seen. When the tube was quite full there was practically no effect. The two models rolled almost together.]

In the actual ship we may have a small quantity of water with plenty of space to move about in, or a larger quantity with less space to move about in. As the empty space gets more and more filled with water the space available for the motion of the water becomes less and less, and ultimately with the ends quite filled with water only a small portion of the upper part of the water can be considered as free to move. The lower part is locked on account of filling the space it occupies.

We must now be quite satisfied that as regards the particular models before us there is a very rapid reduction in the arc of oscillation due to the transverse motion either of free water or a moving solid weight. I want you to infer from what you have seen that the same reduction must always occur in a rolling ship if we have a loose weight of any kind, whether the weight be water or a gun. If this reduction did not take place we should have something to explain which would be quite inexplicable. For suppose we have two ships alike in all respects as regards size, shape, weight, time of oscillation, &c., and situated on precisely the same seas, but one having all her weights properly secured, and the other with a weight capable of traversing the deck every time the ship rolls. If the two vessels were to roll to exactly the same extent we should have the sea not only rolling the ship with the loose weight to the same extent as the ship with all her weights fixed, but the sea would, in addition, be doing all the work involved in the traversing of the heavy weight across the deck, which is quite impossible under the circumstances of perfect similarity we have supposed. The sea can only do the same work on both. In the one case that work consists entirely in rolling the vessel, in the other it consists partly of rolling the ship and partly in dashing the weight about. The rolling in the latter must therefore inevitably be less than in the former case.

Let us apply the same reasoning to our two models. If they were placed in vacuo, and mounted on frictionless pivots, the one without the moving weight would go on swinging for ever. If the other with the moving weight went on swinging for ever also, we should have a perpetual source of energy in the blows caused by the traversing of the weight,—a source which we all know is an impossibility. We should have all the work of hammering which we could apply to do any work we please. Stated in this way the reduction of roll follows as a necessity. The truth is that every time the blow occurs the marble or the water is made a little hotter than it was before, precisely in the same way that the stoppage of a bullet against a target generates enough heat to partially or entirely melt the bullet. All the additional energy in the water or marble due to its increased temperature has had to come from the energy stored up in the oscillating model, and coming from this source has, of course, reduced the extent of oscillation in the manner you have witnessed.

Considerations of the above sort led to the conclusion that although with the ends water-logged, the ship would of necessity have less stability than when intact, yet the resistance to the rolling would be so much increased as to make that stability, degree for degree, much more valuable than when intact, and also make the ship much steadier and consequently render her big guns more formidable.

The power of loose water to reduce the rolling motions of ships having been ascertained experimentally, has been applied on a large scale in the "Inflexible." In this ship a water-chamber has been in successful operation on actual service at sea, and the behaviour of the ship, although very good without the water-chamber in operation, was considerably improved when water was admitted to it. In all the recent designs of English battle ships a space for a water-chamber has been appropriated. The "Admiral" class of vessels has less metacentric height than the "Inflexible" has, and has the same advantage as the "Inflexible" as regards water-chamber. It is quite certain, therefore, that the excellence of behaviour we have had reported from the "Inflexible" will be more than realised in the "Admirals." It is important to bear this in mind, because one class of critic says the central citadel ship may be made perfectly safe against capsizing when the ends are riddled, provided you make your stability when intact so great as to admit of the necessary reduction of stability you incur when your ends are damaged. The stability necessary for this purpose will, however, certainly make your vessel roll much more than you need to make her roll, whereas in the belted system you need only provide as much stability as is necessary for the intact condition. This criticism, however, can have no weight in the face of the favourable reports received as to the behaviour of "Inflexible," the ship which we are quite certain will roll under ordinary circumstances more than any of the "Admirals."

A series of very careful experiments has also been made at Spithead in smooth water on board the "Edinburgh," to ascertain the effect of varying quantities of water in adding to the ship's rolling resistance, and also for ascertaining the best quantity of water to put in the water-chamber. It was found that 100 tons was the best quantity to be used in the water-chamber provided. The best quantity of course varies with the size of water-chamber and other features, such as size of ship, time of swing of ship, &c., and can only be found experimentally in each individual case. It was found that when rolling to 10° the rolling resistance was increased by 43 per cent.

Two feet addition to the bilge keels would add 67 per cent. to the rolling resistance at all angles of roll. The water-chamber is more effective at small angles of rolling than

the bilge keel, and is consequently much more efficacious in bringing the ship to a dead stop than the bilge keel, whose power of stopping the ship gets less and less as the angle lessens. The relative effects of the water-chamber and two feet of additional bilge keel are compared below:—

The water-chamber at	3°	adds 6 times	} as much as 2 feet additional bilge keel.
" "	5°	" 3 "	
" "	12°	" the same	
" "	18°	" one half	

For violent rolling at sea the bilge keel is the more efficient of the two, but for moderate angles of roll in good fighting weather the water-chamber is the more efficient of the two in steadying the guns.

As illustrating still further the effect of moving water in steadying the ship, let us consider the following table prepared by the "Inflexible" Committee:—

—				Range of Roll.	Range of next Roll.	Loss of Range.
				Degrees.	Degrees.	Degrees.
"Sultan"	-	-	-	10	9.6	0.4
"Inconstant"	-	-	-	10	9.2	0.8
"Devastation"	-	-	-	10	8.0	2.0
"Inflexible," intact	-	-	-	10	9.0	1.0
" " riddled and gutted*	-	-	-	10	2.6	7.4
" " in condition f†	-	-	-	10	2.2	7.8

In the four first examples in the above table we have no moving water and a small reduction of range of roll. In these four examples the figures are obtained from the actual ships. In the two last examples the figures have not been obtained from the actual ship, the ship never having been in the condition supposed. These results were obtained from a model ‡ of the vessel, most carefully constructed as to distribution of weight, &c., so as to accurately represent the ship. It was also estimated by the "Inflexible" Committee, on principles that were thoroughly tested by actual trials at sea, Mr. Froude having previously gone to sea on purpose, that if the "Inflexible" were exposed to a series of waves as large as any on record, viz., about one fourth of a mile in length and 40 feet in height, her maximum angle of rolling would be as under:—

Condition of Ship.				Maximum Angle of Ship's Deck with the Horizon.	Maximum Angle of Ship's Deck with Wave Surface.
				Degrees.	Degrees.
Riddled and gutted	-	-	-	2	7½
In condition f	-	-	-	6½	10

The angle of vanishing stability in these two conditions is over 30°, and the Committee reported in consequence that the ship "would possess both buoyancy and stability enough to "enable her to face all contingencies of weather." As regards buoyancy and stability, then, we may rest assured that the central-citadel ship when well designed is perfectly safe, even when her unarmoured ends are freely riddled.

I now proceed to deal with the question of speed. The "Inflexible" Committee reported that in the above extreme conditions of damage the speed may be seriously impaired, but in all other respects the vessel would be able to exercise all her powers. . . . The heel due to her circling at the highest speed attainable would not be an element of danger.

Some persons suppose that the above feature of reduction of speed under extreme conditions of damage is in itself a fatal objection to the adoption of central citadel ships. If this feature were peculiar to central citadel ships it would of course be a very serious objection to them. This defect is, however, by no means peculiar to the central citadel type; it exists also in the belted ship, and to an equally fatal extent, as I shall show. If I were to tell you that when the three main compartments in the hold of a belted ship were bilged the vessel would go down, and that, therefore, the belted type was a bad type, you would say it may be useful to know that the ship would go down under these circumstances, but so would any other ship, and therefore that fact in itself says nothing as regards the badness of type. Your very natural answer is the one I am compelled to adopt. I am very sorry the central citadel ship is liable to the above reduction in speed. I am equally sorry the belted ship is also liable to the same reduction. The belted ship is liable, in addition, to other defects not existing in the central citadel ship, as I now proceed to show.

* "Riddled and gutted" means that the ends are freely penetrated, and the whole of the stores and cork blown out of the ship.

† For condition f, see page 12.

‡ This "model" weighed nearly a ton, which is greater than the weight of many ship's boats.

If we take the case of the two ships *at rest in smooth water* and open a smart fire on them of heavy machine guns and of 6-pr. guns we should admit, if we *completely* destroyed the internal subdivision over the under-water deck, 600 tons of water into the central citadel ship, and the ship ("Camperdown") would sink 14 inches in consequence.* If the destruction of the internal subdivision were less complete, less water would be admitted, and the sinkage would be less than 14 inches. All the damage to the belted ship would be above the top of her belt, which is $2\frac{1}{2}$ feet above water. In this vessel, therefore, there would be no entry of water (under the circumstances supposed of being motionless in smooth water) and no sinkage. Both ships are certain not to capsize. The central citadel ship has sunk 14 inches, the belted has not gone down an inch.

If, now, we were to steam ahead with both ships, and suppose no more water admitted to the citadel ship and none to the other, the central citadel 10,000-ton "Camperdown," would lose one-fourth of a knot due to the 14 inches increase of immersion, and the belted ship would lose nothing. The central citadel ship was able to start with an additional knot over the belted ship on account of being able to put more weight into machinery due to savings from the belt. All the time, therefore, no further water comes in, she is three-fourths of a knot better off than her belted antagonist, notwithstanding she has lost a quarter of a knot and the belted ship has lost nothing.

It is not reasonable, however, to suppose that no more water (under the above circumstances), will come into the central-citadel ship, some of the holes will be scoop shaped and tend to draw water into the ship, and the holes may also be very numerous. It must be admitted that more water *may* come in. It must also be recognised that the complete destruction implied by the admission of the 600 tons referred to above can only be a slow process, during which the belted ship cannot hope to remain undamaged, and whatever may be the amount of water contended as being certain to come into the central citadel ship over and above the preceding 600 tons must also come into the belted ship, because all the time she is steaming at a fighting speed her belt is not $2\frac{1}{2}$ feet above water as it is in harbour, but is more than covered at the stern by the stern wave, and is from 6 to 10 feet under the water at the bow, *see* Fig. 8c. The midship part is also half its time under water on account of the roll of the ship and the passage of waves along her sides, and the tendency of this is, as we have seen on page 9, to accumulate water. The truth is, that so far as the accumulation of water goes, the top of armour is in both cases under water; in the belted ship it is 6 to 10 feet under water at the bow, and in the central-citadel ship it is about 4 feet more. It is just as easy to get water into the belted ship when she is steaming ahead at a fighting speed in a seaway or even in smooth water as it is in the central citadel ship and both must deal with the incoming water in the same way, *i.e.*, allow it to run overboard again through suitable relief scuttles as fast as it comes in or deal with it if possible by the pumps. It is important, too, to bear in mind that during all this time the central ship is steadier than the belted ship, making her big guns more formidable, and as her rolling is reduced by the loose water in her ends water cannot find its way in above the belt amidships so rapidly as in the ship belted during the whole length of her water-line.

If it be contended that the central citadel ship may have all her unarmoured structure destroyed, and that she will then be unable to steam ahead without danger of capsizing, I say you must allow that the belted ship may have all her unarmoured structure destroyed, and here is an experiment to show you that she also cannot steam ahead without certainty of capsizing.† The only inference one can draw from seriously reflecting on the case is either that you must give up contending that these extreme conditions will certainly be realised, or else come to the conclusion that Naval Warfare is impracticable on account of the certainty of destruction of all those engaged in it. There is no choice in this respect between the belt and the central citadel,—both alike will be certain to capsize.

The case, however, is not really as bad as the above. In both types of vessel we have to bear in mind that the holes made are what we might call chance holes. Some are made in some way and some in another. Some on account of their shape and position induce a rapid inflow of water, and some owing to their shape and position induce an equally rapid outflow. The aggregate tendency of the holes to run water into the ship may not, therefore, be very much, but whatever it is, it is the same in both types of vessel and must be dealt with in the same way, *viz.*, the water must be allowed to run out again through holes provided for that purpose in the design of the vessel and opened when occasion requires. It is perfectly true that the limitation of speed pointed out by the "Inflexible" Committee exists in the central citadel type of ship, and must be borne in mind by her Commanding Officer. It is equally true that the same defect exists in the belted ship and must be borne in mind by her Commanding Officer.

* In this statement it is supposed that all the stores are on the under-water deck. In this case the armoured central belt is still 16 inches out of water, with ends completely damaged. If the stores on armoured deck were previously consumed and the vessel riddled, the central belt would have its top 20 inches above water.

† The model of the belted ship previously referred to was allowed to float with a number of shot holes in her upper works, during all the previous part of the lecture, and at this stage was pushed ahead in the tank. The water accumulated in her to such an extent as to capsize her.

Having considered the various points of difference between the central citadel ship and the belted ship item by item, I submit that I have established the following:—

1. That all modern battle ships depend for their stability to a large extent on their unarmoured parts. Their probability of survival in action, so far as stability goes, depends almost entirely on the improbability of the whole or the greater portion of the unarmoured superstructure being completely opened to the sea. The possession of a complete belt along the water-line cannot keep a vessel from capsizing if the unarmoured superstructure is entirely opened to the sea. A belted ship is no safer in this respect, and is less safe in other respects.
2. In the under-water deck system some portion of the superstructure above armour is under water, and is not so easily destroyed, as the above-water portions in the belted system.
3. Although in the under-water deck system it is practically certain that *moderate* quantities of water will be admitted to the ends of the vessel, it is quite certain that the admission of only moderate quantities will not prejudice the stability of the vessel, to an important extent, and will so steady the vessel as to enable her to make good practice with her big guns. On the other hand, it is much more likely that *very large* or *fatal* quantities of water will be admitted to the ends of the belted vessel, and it is also much more likely that the powder and steering gear will be reached in the belted ship by the big gun than in the central citadel ship, because the thin vertical armour on the belt at the ends and the above-water deck over its top are more penetrable to the big gun than the under-water deck of the central citadel ship, well covered as it is by the sea and stores on its top.
4. As regards the loss of speed occasioned by the admission of water, what might be called the smooth-water sinkage of the central citadel ship causes a loss of only one-fourth of a knot in speed, out of an additional knot it was possible to arrange for in the design to start with.
5. As regards the loss of speed due to any supposed rushing in of the water through scoop-shaped holes, it is not a difficult thing to let the water out again by holes suitably shaped and properly positioned; and even if it were, this is a defect which is as great in the belted ship as in the under-water deck ship, because all the time the vessel is steaming at a fighting speed each end of the belt is permanently under water on account of the waves raised by her progress (see Fig. 8e), and the midship part of the belt is half its time under water on account of the rolling of the ship, and the passage of sea waves along her side.
6. That the central citadel system with under-water decks at the ends protects the magazines in the ends of the ship, the steering gear, and supports the ram much better than the belted system does, and at the same time provides on a given weight of armour a very much thicker belt amidships than the belted system does, and as a consequence gives greater protection to the engines and boilers also.
7. That with the central citadel and under-water decks, the admission of water to one end alters the trim so little as to leave it a matter of option and not of necessity with the Commanding Officer whether he will voluntarily admit water to the other end or not. If water be voluntarily admitted to the ends before going into action there can be no further derangement of trim, the vessel will be quite safe, will be almost perfectly steady, and will have lost only one-fourth of a knot in speed out of an additional knot provided for in the original design. See page 17.

In the preceding part of my lectures I have laid great stress on the limitation placed on the Naval Architect as regards the size of his ship, and showed that it was not possible to have a belt the whole length of the water-line on the size adopted, and at the same time to have all the other qualities asked for.

It can hardly be necessary for me to point out that there are two sides to the question of increasing the sizes of ships. The problem of the Naval Administrator must always reduce itself ultimately to that of obtaining the maximum of offensive and defensive power on a given sum of money. The amount of money may be large or small, but he, like everybody else, has to obtain the maximum value for it. Some people contend for having large ships of great powers, and fewer of them; others contend for greater numbers and less individual powers. It would be presumptuous for me to say anything on this point; but I presume you expect me to say something as to the policy of having a belted water-line if the present sizes of ships were considerably increased. I therefore go a step further and say that even with the larger ship and greater amount of armour possible for her to carry it follows from the above summary that, as the belted water-line gives so little advantage as regards some kinds of risk, none at all against others, and involves greater risks in several vital respects than the central citadel system does; it would be much better to employ the additional weight of armour in thickening the decks, the central belt amidships, and particularly in increasing the height of the central citadel armour, than to employ it in making a belt along the whole length of water-line. A

short high belt amidships, where the vessel is broad, costs no more per foot of the ship's length than where the vessel is narrow, but has a much greater value in maintaining the buoyancy and stability than the same armoured area, extending the whole length of the water-line and reaching only $2\frac{1}{2}$ feet above it.

The question of having 2-inch or 3-inch armour on certain parts as a protection against quick-firing guns does not properly come within the scope of the above comparison between the two types. For machine-gun risk both types would be better with such protection, but on a given size of ship would be more vulnerable to the big gun. The development of the machine gun has stopped at its present stage simply on account of the acceptance of thin sides. If a serious attempt were made to defeat the machine gun by thickening the sides of our vessels, the same fight between the machine gun and the armour opposed to it would certainly be gone through, as we have seen in the past evolved from the 68-pr. mounted on truck carriages, and the $4\frac{1}{2}$ inch iron armour of "Warrior." The result of such a fight you are all in as good a position to imagine as I am.

I have endeavoured in the above to bring clearly before you the differences between the two systems of protection. We will now consider in another way the effect of having a complete belt as compared with a central citadel. The table below gives the percentages of the total ship appropriated to each particular item. It will be seen that the completely protected water-line leads to a considerable increase of size, a diminished speed, a diminished weight of armament and of coals. The big guns are also protected to a much less extent than in the central citadel ship, and we have fewer ships in proportion to the total outlay.

	Typical Ship with Short Belt.	Typical Ships with Belts from End to End.	
		No. 1.	No. 2.
	Per-centages.	Per-centages.	Per-centages.
General equipment -	3.5	4.5	2.0
Armament -	8.5	6.5	6.5
Machinery -	13.5	11.0	10.5
Coals -	9.0	6.0	7.0
Armour and backing -	30.0	36.5	38.5
Hull -	35.5	35.5	35.5
Total -	100.0	100.0	100.0
Displacement in tons -	10,000	10,800	11,200
Speed in knots -	16	15	15
Max. thickness of armour -	18 ins.	$21\frac{1}{2}$ ins.	$21\frac{1}{2}$ ins.
Protection of powder passages to barbettes. }	12 ins.	4 ins.	$12\frac{1}{2}$ ins.
Barbette armour -	14 ins. sloping	$15\frac{1}{2}$ ins. vertical.	$16\frac{1}{2}$ ins. vertical.
Principal armament -	4 63-ton guns.	4 48-ton guns.	3 75-ton guns.
Conning tower -	About 90 tons.	Machine gun proof only.	Machine gun proof only.
Nature of protection to loading gear of big gun.	Protected by thick armour.	Protected only by machine gun-proof shields.	Protected only by machine gun-proof shields.

As a further comparison, let us take "Camperdown" and "Dreadnought," which latter ship is shown in Figs. 15 to 15b.

In "Camperdown" we have 18 inches maximum thickness of side armour, four 63-ton guns, 16 knots speed, and a displacement of 10,000 tons.

In "Dreadnought" we have a maximum thickness of armour of only 14 inches, four 38-ton guns, a speed of 14 knots, and a displacement of 10,800 tons. The water-line is protected throughout its length, and the above figures show in what way this protection, imperfect as it is, has had to be paid for.

I will say in conclusion that as a Naval Architect I have been compelled to carefully think over the above subjects for some years past. I have endeavoured to place the various issues before you in a manner devoid of technicalities, and my principal points I have demonstrated experimentally. I thank you very much for the earnest attention you have paid me, but at the same time feel it my duty to warn you that many more than the two hours we have spent together on the subject must be devoted to it by any person before his opinion can be of much value.



